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L4	(measur$3 or determin$3 or calculat$3 or comput$3) same (roll angle)	897	L4
L3	(measur$3 or determin$3 or calculat$3 or comput$3) same (yaw near1 rate)	1084	L3
L2	(measur$3 or determin$3 or calculat$3 or comput$3) same (lateral acceleration)	1245	L2
L1	(measur$3 or determin$3 or calculat$3 or comput$3) same (roll near1 rate)	429	L1

END OF SEARCH HISTORY

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L1: Entry 6 of 8 File: USPT Feb 20, 2001

DOCUMENT-IDENTIFIER: US 6192305 B1
TITLE: Vehicle rollover sensing using yaw rate estimation

Abstract Text (1):
A rollover sensing apparatus and method are provided for predicting rollover or pitchover conditions of a vehicle. The apparatus and method sense angular roll rate, angular pitch rate, longitudinal acceleration, lateral acceleration, and vertical acceleration of the vehicle and produce output signals indicative thereof. A non-linear filter, such as an extended Kalman filter, estimates a current roll angle and a current pitch angle as a function of the sensed signals. A predictor predicts a future roll angle as a function of the estimated current roll angle and the sensed roll rate, and further predicts a future pitch angle as a function of the estimated current pitch angle and the sensed pitch rate. The predicted roll and pitch attitude angles are compared to a threshold value and a vehicle overturn condition signal is output to indicate a predicted vehicle rollover or pitchover condition. In addition, the measured pitch rate and roll rate signals are corrected to compensate for yaw-induced error that may be present.

Brief Summary Text (5):
More recently, sophisticated rollover sensing approaches have been considered. One such approach considered requires the use of six sensors including three accelerometers and three angular rate sensors, also referred to as gyros, all of which are employed together for use in an inertial navigation system which tracks position and attitude of the vehicle. The three accelerometers generally provide lateral, longitudinal, and vertical acceleration measurements of the vehicle, while the three gyros measure pitch rate, roll rate, and yaw rate. However, the more sophisticated rollover sensing approaches generally require a large number of high-precision and expensive sensors. In addition, known sophisticated systems are susceptible to cumulative drift errors, and therefore must be reset occasionally.

Brief Summary Text (6):
It is, therefore, one object of the present invention to provide for vehicle rollover and pitchover sensing that requires minimal sensed measurement parameters and is relatively immune to errors generally found in conventional automotive-grade sensors. It is another object of the present invention to provide for vehicle rollover sensing for an automotive vehicle that may predict a future rollover condition in advance to allow time to deploy occupant protection measures. It is a further object of the present invention to provide for reliable vehicle rollover sensing in a low-cost sensing module. Yet, it is also another object of the present invention to achieve vehicle rollover sensing that corrects signal measurements to correct for errors caused by the vehicle experiencing yaw rate.

Brief Summary Text (8):
In accordance with the teachings of the present invention, a vehicle rollover sensing apparatus and method are provided for predicting an overturn condition of a vehicle. The apparatus includes an angular roll rate sensor for sensing roll rate of the vehicle and an angular pitch rate sensor for sensing pitch rate of the vehicle. The apparatus also includes a longitudinal accelerometer for measuring longitudinal acceleration of the vehicle, a lateral accelerometer for measuring lateral acceleration of the vehicle, and a vertical accelerometer for measuring vertical acceleration of the vehicle. The apparatus further receives a vehicle speed signal indicative of speed of the vehicle. A processor receives the signals and estimates a roll angle and a pitch angle as a function of the received signals. The processor

estimates a yaw rate of the vehicle as a function of lateral acceleration and vehicle speed and determines a pitch rate correction value as a function of the estimated yaw rate and the estimated roll angle and further corrects the measured pitch rate signal based on the pitch correction value. The processor also predicts a future pitch angle as a function of the estimated pitch angle and the corrected pitch rate and compares the predicted pitch angle to a threshold value. An output is provided for deploying a vehicle overturn condition based on the comparison.

Brief Summary Text (9):
In addition or alternately, the processor determines a roll rate correction value as a function of the estimated yaw rate and the estimated pitch angle and corrects the measured roll rate signal based on the roll correction value. The processor further predicts a future roll angle as a function of the estimated roll angle and the corrected roll rate and compares the predicted roll angle to a threshold value to predict a rollover condition of the vehicle. An output is provided for deploying a vehicle overturn condition based on the comparison.

Brief Summary Text (10):
A method is also provided for predicting an overturn condition of a vehicle. The method includes sensing angular roll rate and angular pitch rate of a vehicle. The method further senses longitudinal acceleration, lateral acceleration, and vertical acceleration of the vehicle. The method further receives a vehicle speed signal indicative of speed of the vehicle. A roll angle and pitch angle are estimated as a function of the received signals, and a yaw rate of the vehicle is estimated as a function of lateral acceleration and the vehicle speed signal. The method further determines a pitch rate correction value as a function of the estimated yaw rate and the estimated roll angle and corrects the measured pitch rate signal based on the pitch corrected value. A future pitch angle is predicted as a function of the estimated pitch angle and corrected pitch rate and compared to a threshold value. The method deploys a vehicle overturn condition output based on the comparison step.

Brief Summary Text (11):
In addition or alternately, the method determines a roll correction value as a function of the estimated yaw rate and the estimated pitch angle and corrects the measured roll rate signal based on the roll correction value. The method further includes the steps of predicting a future roll angle as a function of the estimated roll angle and the corrected roll rate and comparing the predicted roll angle to a roll threshold value and deploying an output based on the roll comparison.

Drawing Description Text (16):
FIG. 14 is a flow diagram illustrating a methodology for providing correction to the measured pitch rate and measured roll rate signals for use in predicting a rollover or pitchover condition of a vehicle according to the second embodiment of the present invention; and

Detailed Description Text (9):
Vehicle rollover prediction algorithm 80 receives a longitudinal acceleration signal a.sub.x 82 from the longitudinal accelerometer 18, a lateral acceleration signal a.sub.y 84 from the lateral accelerometer 14, and a vertical acceleration signal a.sub.z from the vertical accelerometer 20. In addition, vehicle rollover prediction algorithm 80 receives a pitch angular rate signal {tilde over (.theta.)} 88 from the pitch angular rate sensor 16 and a roll angular rate signal {tilde over (.phi.)} 90 from the roll angular rate sensor 12. The rollover prediction algorithm 80 utilizes measured acceleration and angular rate signals 82 through 90 together to produce the estimated current roll and pitch angles .phi. and .theta. and to further predict a vehicle rollover or pitchover condition of the vehicle. Generally speaking, the vehicle rollover prediction algorithm 80 preferably requires acceleration signals along the vehicle's longitudinal axis, lateral axis, and vertical axis, as well as pitch and roll angular rate signals.

Detailed Description Text (10):
Rollover prediction algorithm 80 averages each of the measured vehicle acceleration and angular rate signals 82 through 90 over a one-second time interval, according to one example. More particularly, average blocks 92 through 96 perform a one-second

average of the corresponding measured longitudinal acceleration signal a.sub.x 82, lateral acceleration signal a.sub.y 84, and vertical acceleration signal a.sub.z, 86, respectively. Likewise, average acceleration and attitude angles are modelled using discrete-time kinematic models driven by white noise. The longitude, latitude, and vertical acceleration components a.sub.x, a.sub.y, and a.sub.z, respectively, and the angular pitch and rate angles [- - - Unable To Translate Graphic - - -] and [- - - Unable To Translate Graphic - - -] equations may be as provided as follows:

Detailed Description Text (14):
The time averaged acceleration and angular rate signals are input to an extended Kalman filter 102. In effect, the extended Kalman filter 102 estimates both the current roll angle .phi. and the current pitch angle .theta. as a function of the vehicle's measured longitudinal acceleration, lateral acceleration, vertical acceleration, pitch angular rate, and roll angular rate. The extended Kalman filter 102 is a thirteenth-order, non-linear filter which is based on (1) the selection of physical quantities to be represented by state variables in the filter; (2) the dynamic models chosen to represent the interaction in time-evolution of the state variables; and (3) the measurement model chosen to represent how the available measurements are related to the values taken by the physical quantities represented in the state factors. The extended Kalman filter 102 handles non-linearities in the models, particularly in the measurement model. In connection with rollover prediction algorithm 80, the physical quantities represented in the extended Kalman filter 102 include three earth-based components of acceleration A.sub.x, A.sub.y, and A.sub.z, the roll and pitch attitude angles .phi. and .theta., and the sensor biases for each of the five sensors. The acceleration and attitude angles are modelled using discrete-time kinematic models driven by white noise. The longitude, latitude, and vertical acceleration components a.sub.x, a.sub.y, and a.sub.z, respectively, and the angular pitch and rate angles .theta. and .phi. equations may be as provided as follows:

Detailed Description Text (18):
The roll and pitch angle estimates .phi..sub.EkF and .theta..sub.EkF coming out of the extended Kalman filter 102 are piece-wise constant, generally changing every extended Kalman filter loop time interval. To achieve roll and pitch angle estimates .phi. and .theta. which are valid in the interior of the extended Kalman filter time interval, the time integrals of the sensed angular roll and pitch rates {tilde over (.phi.)} and {tilde over (.theta.)} are used. This is achieved by using integrators 108 and 110. The extended Kalman filter 102 determines bias associated with each of the measured signals input thereto. The bias signals determined for the pitch angular rate and roll angular rate signals are output and identified as b.sub..theta. and b.sub..phi., respectively. Roll rate bias signal b.sub..phi. is subtracted from the measured roll angular rate signal {tilde over (.phi.)} via summing junction 106 and input to integrator 110. Likewise, pitch rate bias signal b.sub..theta. is subtracted from the measured pitch angular rate signal {tilde over (.THETA.)} via summing junction 104 and input to integrator 108. Accordingly, integrators 108 and 110 receive bias corrected pitch and rate signals every sensor measurement interval. In addition, integrators 108 and 110 receive the estimate of pitch angle .phi..sub.EkF and roll angle .theta..sub.EkF from the extended Kalman filter 102 every extended Kalman filter loop time. To get attitude angle estimates which are valid in the interior of the extended Kalman filter loop time interval, the integral of the sensed angular rates are used, being reset at the beginning of each filter loop time interval to the estimated roll or pitch angle values .phi..sub.EkF or .theta..sub.EkF indicated by the extended Kalman filter 102. Accordingly, integrators 108 and 110 output an updated estimate of current pitch angle .theta. and an updated estimate of current roll angle .phi..

Detailed Description Text (19):
With particular reference to FIG. 2B, rollover prediction algorithm 80 employs a pair of Taylor series predictors, particularly first Taylor series predictor 116 and second Taylor series predictor 118. The first Taylor series predictor 116 receives the estimated current pitch angle .theta. output from integrator 108, the measured pitch angular rate signal {tilde over (.theta.)} and an estimated current pitch acceleration {circumflex over (.theta.)}. The estimated current pitch acceleration {circumflex over (.theta.)} is produced via filter 112, which performs a derivative

calculation on the measured pitch angular rate signal {tilde over (.theta.)}. The Taylor series predictor 116 generates the predicted pitch angle .theta..sub.T as a function of the estimated pitch acceleration {circumflex over (.theta.)}, the pitch rate {tilde over (.theta.)}, and the estimated pitch angle .theta.. With the Taylor series predictor 116, the vehicle rollover prediction algorithm 80 predicts a pitch angle .theta..sub.T an advance time T into the future. The pitch angle time-history in the neighborhood of the current time is approximated by the Taylor series predictor 116 as a weighted sum, which may be approximated as follows:

Detailed Description Text (20):
The Taylor series prediction of the predicted pitch angle .theta..sub.T is therefore a function of the estimate of the current pitch angle .theta. summed with the product of the desired warning time T and the measured current value of the pitch rate {tilde over (.theta.)}, and further summed with the product of the desired warning time squared and the estimate of the current pitch acceleration {tilde over (.theta.)} divided by two.

Detailed Description Text (21):
The Taylor series predictor 118 generates the predicted roll angle .phi..sub.T as a function of the estimated roll acceleration {tilde over (.phi.)}, the measured roll rate {tilde over (.phi.)}, and the estimated roll angle .phi. output from integrator 110. With the Taylor series predictor 118, the vehicle rollover prediction algorithm 80 predicts a roll angle .phi..sub.T an advance time T into the future. The roll angle time-history in the neighborhood of the current time is approximated by the Taylor series predictor 118 as a weighted sum, which may be approximated as follows:

Detailed Description Text (22):
The Taylor series prediction of the predicted roll angle .phi..sub.T is therefore a function of the estimate of the current roll angle .phi. summed with the product of the desired warning time T and the measured current value of roll rate {tilde over (.phi.)}, and further summed with the product of the desired warriing time squared and the estimate of the current roll acceleration {tilde over (.phi.)} divided by two. Units for the above equations are radians, seconds, radians-per-second, and radians-per-second squared. The desired warning time may be equal to 500 milliseconds, according to one example, so that enough advance warning is provided to deploy the necessary safety restraint device prior to the actual vehicle rollover condition occurring and before the occupants are too far out of position. Accordingly, the aforementioned Taylor series prediction equations show that the Taylor series approximation is evaluated according to an advance warning time T. While the above Taylor series prediction equations are shown as second order equations, it should also be appreciated that first order equations may be employed, such that the predicted roll angle .phi..sub.T is equal to the estimated roll angle .phi. summed with the product of the desired warning time T and measured current roll rate {circumflex over (.phi.)}. and such that the predicted pitch angle .theta..sub.T is equal to the estimated pitch angle .theta. summed with the product of the desired warning time T and measured current pitch rate {circumflex over (.theta.)}.

Detailed Description Text (23):
The absolute value of the predicted pitch angle .theta..sub.T is compared with a programmed pitch deployment threshold .theta..sub.0 122 by way of comparator 120. Deployment threshold .theta..sub.0 122 is a programmed, predetermined threshold value that is used to determine the prediction of a pitchover condition. According to one example, deployment pitch threshold .theta..sub.0 122 is set equal to approximately seventy degrees (70.degree.). Comparator 120 produces a pitch deployment output signal 52 indicative of a predicted rollover condition, when the predicted pitch angle .theta..sub.T is greater than the deployment pitch threshold .theta..sub.0 122.

Detailed Description Text (24):
The absolute value of the predicted roll angle .phi..sub.T is compared with a programmed deployment roll threshold .phi..sub.0 126 by way of comparator 124. Deployment roll threshold .phi..sub.0 126 is a programmed predetermined threshold value that is used to determine the prediction of a rollover condition. According to

one example, deployment threshold .phi..sub.0 126 is set equal to approximately fifty degrees (50.degree.). Comparator 124 produces a rollover output signal 50 indicative of a predicted rollover condition, when the predicted roll angle .phi..sub.T is greater than the deployment roll threshold .phi..sub.0 126. The generated rollover output signal 50 and pitchover output signal 52 may be employed by any one or more selected devices to deploy occupant safety restraint devices or carry out other functions, as desired.

Detailed Description Text (27):
In addition, model 130 further includes a measurement model identified as block 150, which receives inputs from each of the kinematic models 132-138. Additionally, measurement model 150 receives white noises 170 which represent noises in the measurement of each of the quantities that are being measured, including lateral acceleration, longitudinal acceleration, vertical acceleration, roll angular rate, and pitch angular rate, when attending to an overturn condition. The measurement is modeled as being whatever the true values of those measured values are, plus some unknown noise value. The measurement model 150 produces model outputs for the measured acceleration values a.sub.x, a.sub.y, and a.sub.z as well as the measured roll rate {tilde over (.phi.)} and the measured pitch rate {tilde over (.theta.)}. The measurement model 150 may be represented by the measurement models illustrated in FIGS. 4-10, and described hereinafter.

Detailed Description Text (37):
Referring to the slow loop time process, methodology 270 checks to see if it is time to run the extended Kalman filter 102 pursuant to decision block 276. The decision to run the extended Kalman filter occurs at approximately every one-second time interval. If the slow loop time of one second has elapsed, methodology 270 proceeds to run the extended Kalman filter pursuant to block 278. One loop of the extended Kalman filter is run using the measurements averaged over the previous one-second interval as determined by average blocks 92 through 100. The loop time includes both a time-update and a measurement-update and produces estimates of roll and pitch angles, as well as bias estimates for each of the sensors. Next, pursuant to block 280, methodology 270 resets the roll and pitch angle estimates .phi..sub.EkF and .theta..sub.EKF input to integrators 110 and 108, respectively, to the newly calculated estimate values as determined by the extended Kalman filter 102. The values in the roll and pitch angle integrators 110 and 108 are thereby replaced by the latest roll angle and pitch angle estimates produced by the extended Kalman filter. Until the next time the extended Kalman filter runs, the roll and pitch angle estimates contained in integrators 110 and 108 will be updated with the fast loop time process using the bias-corrected roll and pitch rates as will be discussed hereinafter. To complete the slow loop time process, block 282 resets the five measurement averagers 92 through 100 back to zero, which allows the extended Kalman filter 102 in the next slow loop to have as inputs the averages of the five measurements over the preceding slow loop time interval of one second. Methodology 270 continues to run the slow loop time process every one second.

Detailed Description Text (38):
With respect to the fast process loop, methodology 270 proceeds to decision block 284 to check to see if a fast loop time interval has elapsed, indicating that it is time to run the fast loop process of methodology 270. Once the fast loop time has elapsed, block 286 measures the longitudinal, lateral, and vertical accelerations and the pitch and roll angular rates. The values output from the five sensors are recorded. In block 288, each of the averagers 92 through 100 records the average value of its respective measurement input over the time interval beginning with the last time the slow loop was entered, i.e., each one second. Next, in block 290, the latest measured values of roll rate and pitch rate are corrected using the latest estimates of roll angular rate bias b.sub..phi. and pitch angular rate bias b.sub..theta. outputs from the extended Kalman filter 102.

Detailed Description Text (39):
Methodology 270 proceeds to block 292 to update the roll and pitch angular integrators 110 and 108. For both the roll and pitch, the product of the fast loop time and the respective bias-corrected angular rate is added into the value held by the corresponding integrator 108 or 110. The integrator values serve as the estimates for the current roll and pitch angles .phi. and .theta.. In addition,

methodology 290 estimates the roll and pitch angular accelerations as provided in block 294. A separate, simple Kalman filter may be used to estimate the time-derivatives of the bias-corrected measured roll rate and pitch rate signals to provide the estimated roll and pitch accelerations.

Detailed Description Text (40):
Given the estimated roll and pitch angles, roll and pitch accelerations, and measured roll and pitch angular rates, methodology 270 calculates the predicted roll and pitch angles .phi..sub.T and .theta..sub.T pursuant to block 296. The predicted roll angle .phi..sub.T is calculated by taking a weighted sum of the estimated roll angle, the roll rate, and the estimated roll acceleration. Likewise, the predicted pitch angle .theta..sub.T is calculated by taking a weighted sum of the estimated pitch angle, the pitch rate, and the estimated pitch acceleration. The weights in the weighted sum are essentially calibrations. Proceeding to decision block 298, methodology 270 checks to see if the predicted roll and pitch angles exceed the corresponding roll and pitch limits. The predicted roll and pitch angles are each checked to see if either of their magnitudes exceed the corresponding calibration threshold. According to one example, the predicted roll angle .phi..sub.T is compared to a threshold of fifty degrees (50.degree.), while the predicted pitch angle .theta..sub.T is compared to a threshold angle of seventy degrees (70.degree.). If neither of the pitch or roll angles exceed the corresponding threshold limits, methodology 270 returns to the beginning of the fast process loop. Otherwise, if either of the predicted roll or pitch angles exceeds the corresponding limits, methodology 270 predicts that a future rollover event is to occur and proceeds to block 300. The predicted rollover output may then be used to signal deployment of safety-restraint devices, as provided in block 300, so as to actuate, for example, a pop-up roll bar, a seat belt pretensioner, an air bag, or other selected devices. Following signalling of the deployment of the devices, methodology 270 is complete pursuant to stop block 302.

Detailed Description Text (45):
According to a second embodiment of the present invention, the vehicle rollover prediction methodology further estimates vehicle yaw rate and computes a correction to the measured pitch rate signal {tilde over (.theta.)} and a correction to the measured roll rate signal {circumflex over (.phi.)}. The calculated pitch rate and roll rate corrections provide enhanced accuracy pitch rate and roll rate signals which in turn improves the estimations of the vehicle's pitch angle and roll angle, respectively, particularly for conditions in which the vehicle experiences yaw rate. It has been discovered that under some conditions, the estimated pitch angle may drift away from the vehicle's actual pitch angle as the vehicle experiences yaw rate, particularly when the vehicle travels along a curve. In addition, it has also been discovered that the estimated roll angle may also drift away from the vehicle's actual roll angle when the vehicle experiences yaw rate. Under such a condition, the vehicle will generally roll outwardly and tilt relative to the ground. The sharper the turn and the faster the vehicle speed, generally the greater the amount of tilt experienced by the vehicle. As a consequence, the dynamics inducing the tilt may lead to a false measurement by the pitch angular rate sensor 16 and roll angular rate sensor 12.

Detailed Description Text (46):
Referring to FIG. 13, the rollover prediction algorithm 80 of FIGS. 2A and 2B is shown to the extent as modified and is identified as rollover prediction algorithm 80' according to the second embodiment of the present invention. Rollover prediction algorithm 80' is similar to algorithm 80 shown in FIGS. 2A and 2B, with the addition of pitch rate and roll rate correction as described hereinafter. More particularly, rollover prediction algorithm 80' includes a calculate pitch rate correction block 310 for calculating a pitch rate correction value and a summing junction 312 for subtracting the calculated pitch rate correction value from the measured pitch rate signal. The calculate pitch rate correction block 310 receives as inputs the measured vehicle speed signal (VSS), the estimated roll angle .phi..sub.EKF as provided by the extended Kalman filter, and the estimated earth-lateral acceleration A.sub.y as determined by the extended Kalman filter. Accordingly, the measured vehicle speed signal (VSS), estimated roll angle, and estimated earth-lateral acceleration values are processed to calculate the pitch rate correction value. The calculated pitch rate correction value is then subtracted from the measured pitch

rate signal {tilde over (.theta.)} that is generated by the pitch angular rate sensor 16. This pitch rate correction technique reduces measurement errors and provides for enhanced accuracy pitch rate measurement which leads to an improved estimation of the pitch angle, particularly when the vehicle experiences yaw rate.

Detailed Description Text (47):
Rollover prediction algorithm 80' further includes a calculate roll rate correction block 314 for calculating a roll rate correction value and a summing junction 316 for subtracting the calculated roll rate correction value from the measured roll rate signal. The calculate roll rate correction block 314 receives as inputs the measured vehicle speed signal (VSS), the estimated pitch angle .theta..sub.EKF as determined by the extended Kalman filter, and the estimated earth-lateral acceleration A.sub.Y as determined by the extended Kalman filter. Accordingly, the measured vehicle speed signal (VSS), estimated pitch angle, and estimated earth-lateral acceleration values are processed to calculate the roll rate correction value. The calculated roll rate correction value is then subtracted from the measured roll rate signal {tilde over (.phi.)} that is generated by the roll angular rate sensor 12. This roll rate correction technique reduces measurement errors and provides enhanced accuracy roll rate measurement which leads to improved estimation of the roll angle, particularly when the vehicle experiences yaw rate.

Detailed Description Text (48):
Referring particularly to FIG. 14, a pitch and roll rate methodology 320 is illustrated for correcting measured pitch rate and roll rate, and is particularly provided to correct for yaw-induced errors, according to the present invention. Methodology 320 begins with step 322 in which the speed of the vehicle is measured with a speed sensor to produce the vehicle speed signal (VSS). Next, in step 324, methodology 320 checks to see if the vehicle speed signal is indicative of a vehicle speed greater than a predetermined low speed threshold of five miles-per-hour (5 mph), according to one example. If the vehicle speed does not exceed the predetermined low speed threshold, methodology 320 proceeds to set both the pitch rate correction value and roll rate correction value to zero pursuant to step 326, and then returns to step 322 to measure the vehicle speed.

Detailed Description Text (49):
If the vehicle speed is greater than the predetermined low speed threshold value, methodology 320 proceeds to estimate the yaw rate of the vehicle as a function of the estimated earth-lateral acceleration and vehicle speed as provided in step 328. More particularly, the estimated yaw rate is determined by dividing the estimated earth-lateral acceleration by the vehicle speed. According to this approach, the vehicle yaw rate estimation does not require a yaw gyro. Once the estimated yaw rate is computed, the pitch rate correction value is calculated as a function of estimated yaw rate and the estimated roll angle as provided in step 330. More particularly, the pitch rate correction value is calculated by multiplying the estimated yaw rate by the estimated roll angle. Once the calculated pitch rate correction value is determined, the pitch rate correction value is subtracted from the measured pitch rate signal as received from the pitch angular rate sensor 16 according to step 332.

Detailed Description Text (50):
In addition, rate correction methodology 320 further calculates the roll rate correction value as a function of the estimated yaw rate and estimated pitch angle as shown in step 334. More particularly, the roll rate correction value is calculated by multiplying the negative of the estimated yaw rate with the estimated pitch angle. Once the roll rate correction value is calculated, the roll rate correction value is subtracted from the measured roll rate signal that is received from roll angular rate sensor 12 pursuant to step 336.

Detailed Description Text (51):
Accordingly, methodology 320 calculates pitch rate and roll rate correction values and subtracts the corresponding correction values from the measured pitch rate and roll rate signals to realize a more accurate pitch rate and roll rate, despite the presence of any yaw-induced error. The corrected pitch rate and roll rate signals are then used to estimate the pitch angle and roll angle, respectively, as described above. The pitch angle and roll angle estimations are employed to predict if a

rollover or pitchover condition of the vehicle is likely to occur.

Detailed Description Text (55):
Where the estimated yaw rate {circumflex over (.gamma.)} is multiplied by the estimated pitch angle .theta. and summed with the measured roll rate {tilde over (.phi.)} to provide the corrected roll rate. For pitch rate correction, the estimated yaw rate, {circumflex over (.gamma.)} is multiplied by both the sine of the estimated roll angle .phi. and the cosine of the estimated pitch angle .theta. and subtracted from the measured pitch rate {tilde over (.theta.)}, and further divided by cosine of the estimated roll angle .phi.. The inclusion of sine and cosine computations may provide for enhanced roll rate correction and pitch rate correction. On the other hand, the use of small-angle approximations, which assumes the cosine of x is approximately equal to one and the sine of x is approximately equal to x for small angles, avoids the calculation of sine and cosine functions and further eliminates a division operation with respect to the pitch rate correction to allow for fewer calculations.

Detailed Description Text (56):
According to a further aspect of the present invention, the rollover prediction methodology 270 for predicting a vehicle rollover or pitchover condition may further include the step 340 of scale-correcting the measured angular roll rate and pitch rate signals as illustrated in FIG. 15. It should be appreciated that methodology 270 bias-corrects the roll rate and pitch rate signals as is provided in block 290. The bias correction of block 290 compensates for any calibration offset that may be present in the roll and pitch angular rate sensors 12 and 16. Similar to bias correction, the scale-correct roll and pitch rate step 340 corrects for the appropriate scaling of the roll and pitch angular rate sensors 12 and 16. The scaling factor is a multiplication factor that for a number of reasons could be out of scale for the roll and/or pitch angular rate sensors due to a number of possible causes. For example, temperature changes, manufacturing tolerance variations, or other variations in manufactured angular rate sensors may lead to variations in sensor scaling. To accommodate for such scaling differences, the added step scale-correction provides scaling to adjust the sensor outputs to a more accurate scaling factor.

Detailed Description Text (57):
The step 340 of scale-correcting the roll rate and pitch rate signals may be provided similar to the bias-corrected roll and pitch rates as described in connection with the modeling provided for bias-correction. In so doing, the bias signals are preferably replaced with scaling signals, and instead of providing an additive offset as is the case for a bias-correction, the scale-correction requires a multiplication scaling factor applied to the measured signals to realize scaling correction.

CLAIMS:

1. A rollover sensing apparatus for predicting an overturn condition for a vehicle, comprising:

an angular roll rate sensor for sensing roll rate of a vehicle and producing an output signal indicative thereof;

an angular pitch rate sensor for sensing pitch rate of the vehicle and producing an output signal indicative thereof;

a longitudinal accelerometer for measuring longitudinal acceleration of the vehicle and producing an output signal indicative thereof;

a lateral accelerometer for measuring lateral acceleration of the vehicle and producing an output signal indicative thereof;

a vertical accelerometer for measuring vertical acceleration of the vehicle and producing an output signal indicative thereof;

a vehicle speed signal indicative of speed of the vehicle;

a processor for receiving said signals and for estimating a roll angle and a pitch angle as a function of said received signals, said processor estimating a yaw rate of the vehicle as a function of lateral acceleration and said vehicle speed signal, and determining a pitch rate correction value as a function of said estimated yaw rate and said estimated roll angle and further correcting said measured pitch rate signal based on said pitch correction value, and said processor predicting a future pitch angle as a function of said estimated pitch angle and said corrected pitch rate and comparing said predicted pitch angle to a threshold value; and

an output for deploying a vehicle overturn condition output based on said comparison.

2. The apparatus as defined in claim 1, wherein said processor further determines a roll rate correction value as a function of said estimated yaw rate and said estimated pitch angle, and corrects said measured roll rate signal based on said roll correction value, said processor further predicting a future roll angle as a function of said estimated roll angle and said corrected roll rate and comparing said predicted roll angle to a threshold value to predict a rollover condition.

5. The apparatus as defined in claim 1, wherein said pitch rate correction value is determined as a function of said estimated yaw rate multiplied by said estimated roll angle.

10. A rollover sensing apparatus for predicting an overturn condition for a vehicle, comprising:

an angular roll rate sensor for sensing roll rate of a vehicle and producing an output signal indicative thereof;

an angular pitch rate sensor for sensing pitch rate of the vehicle and producing an output signal indicative thereof;

a longitudinal accelerometer for measuring longitudinal acceleration of the vehicle and producing an output signal indicative thereof;

a lateral accelerometer for measuring lateral acceleration of the vehicle and producing an output signal indicative thereof;

a vertical accelerometer for measuring vertical acceleration of the vehicle and producing an output signal indicative thereof;

a vehicle speed signal indicative of speed of the vehicle;

a processor for receiving said signals and for estimating a roll angle and a pitch angle as a function of said received signals, said processor estimating a yaw rate of the vehicle as a function of lateral acceleration and said vehicle speed signal, and determining a roll rate correction value as a function of said estimated yaw rate and said estimated pitch angle and further correcting said measured roll rate signal based on said roll correction value, and said processor predicting a future roll angle as a function of said estimated roll angle and said corrected roll rate and comparing said predicted roll angle to a threshold value; and

an output for deploying a vehicle overturn condition output based on said comparison.

11. The apparatus as defined in claim 10, wherein said processor further determines a pitch rate correction value as a function of said estimated yaw rate and said estimated roll angle, and corrects said measured pitch rate signal based on said pitch correction value, said processor further predicting a future pitch angle as a function of said estimated pitch angle and said corrected pitch rate and comparing said predicted pitch angle to a threshold value to predict a pitchover condition.

14. The apparatus as defined in claim 10, wherein said roll rate correction value is determined as a function of said estimated yaw rate multiplied by said estimated

pitch angle.

16. An apparatus for estimating a yaw corrected attitude rate of a vehicle comprising:

an angular roll rate sensor for measuring roll rate of a vehicle and producing an output signal indicative thereof;

an angular pitch rate sensor for measuring pitch rate of the vehicle and producing an output signal indicative thereof;

a longitudinal accelerometer for measuring longitudinal acceleration of the vehicle and producing an output signal indicative thereof;

a lateral accelerometer for measuring lateral acceleration of the vehicle and producing an output signal indicative thereof;

a vertical accelerometer for measuring vertical acceleration of the vehicle and producing an output signal indicative thereof;

a vehicle speed signal indicative of speed of the vehicle; and

a processor for estimating yaw rate of the vehicle as a function of lateral acceleration and said vehicle speed signal, and determining an angular rate correction value as a function of said estimated yaw rate and an estimated attitude angle, said processor further subtracting said determined angular rate correction value from said measured attitude rate to provide a yaw corrected attitude rate.

19. A method for predicting an overturn condition of a vehicle, said method comprising the steps of:

sensing angular roll rate of a vehicle and producing an output signal indicative thereof;

sensing angular pitch rate of the vehicle and producing an output signal indicative thereof;

sensing longitudinal acceleration of the vehicle and producing an output signal indicative thereof;

sensing lateral acceleration of the vehicle and producing an output signal indication thereof;

sensing vertical acceleration of the vehicle and producing an output signal indicative thereof;

receiving a vehicle speed signal indicative of speed of the vehicle;

estimating a roll angle and a pitch angle as a function of said received signals;

estimating a yaw rate of the vehicle as a function of lateral acceleration and said vehicle speed signal;

determining a pitch rate correction value as a function of said estimated yaw rate and said estimated roll angle;

correcting said measured pitch rate signal based on said pitch corrected value;

predicting a future pitch angle as a function of said estimated pitch angle and said corrected pitch rate;

comparing said predicted pitch angle to a threshold value; and

deploying a vehicle overturn condition output based on said comparison step.

20. The method as defined in claim 19, further comprising the steps of:

determining a roll rate correction value as a function of said estimated yaw rate and said estimated pitch angle;

correcting said measured roll rate signal based on said roll correction value;

predicting a future roll angle as a function of said estimated pitch angle and said corrected roll rate;

comparing said predicted roll angle to a roll threshold value; and

deploying a vehicle overturn condition output based on said roll comparison.

22. The method as defined in claim 19, wherein said step of determining pitch rate correction value includes multiplying said estimated aw rate by said estimated roll angle.

24. A method for predicting an overturn condition of a vehicle, said method comprising the steps of:

sensing angular roll rate of a vehicle and producing an output signal indicative thereof;

sensing angular pitch rate of the vehicle and producing an output signal indicative thereof;

sensing longitudinal acceleration of the vehicle and producing an output signal indicative thereof;

sensing lateral acceleration of the vehicle and producing an output signal indication thereof;

sensing vertical acceleration of the vehicle and producing an output signal indicative thereof;

receiving a vehicle speed signal indicative of speed of the vehicle;

estimating a roll angle and a pitch angle as a function of said received signals;

estimating a yaw rate of the vehicle as a function of lateral acceleration and said vehicle speed signal;

determining a pitch rate correction value as a function of said estimated yaw rate and said estimated roll angle;

correcting said measured pitch rate signal based on said pitch correction value;

predicting a future pitch angle as a function of said estimated pitch angle and said corrected pitch rate;

comparing said predicted pitch angle to a threshold value; and

deploying a vehicle overturn condition output based on said comparison step.

25. The method as defined in claim 24, further comprising the steps of:

determining a roll rate correction value as a function of said estimated yaw rate and said estimated pitch angle;

correcting said measured roll rate signal based on said roll correction value;

predicting a future roll angle as a function of said estimated roll angle and said corrected roll rate;

comparing said predicted roll angle to a roll threshold value; and

deploying a vehicle overturn condition output based on said roll comparison step.

27. The method as defined in claim 24, wherein said step of determining pitch rate correction value includes multiplying said estimated yaw rate by said estimated roll angle.